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EVALUATION OF WORD INTELLIGIBILITY OF TWO MODULATOR/DEMODULATOR--ETC(U)
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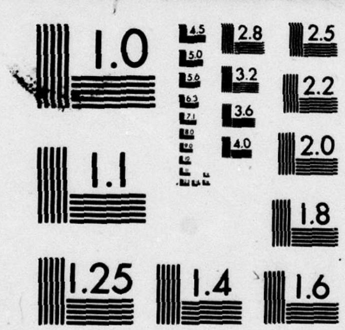

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The communication effectiveness of words processed through two modems of a spread spectrum radio system during various jamming conditions was measured in the presence of the simulated noise of an aircraft cockpit. Results indicate that the intelligibility of words processed through the two modems is differentially affected at various jammer-signal (J/S) power ratios by the presence of the simulated F-15A cockpit noise. Word intelligibility decreased with corresponding increases in the J/S power ratio, although the effect is not a

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simple one, i.e., it is not the same at all J/S levels. It is also indicated that high levels of the simulated cockpit noise produce greater decrements in word intelligibility than low levels for all the J/S power ratios evaluated. The importance of evaluating potential Air Force voice communication systems in as realistic an acoustical environment as practical is emphasized.

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INTRODUCTION

Sustained effective voice communication is a vital requirement in modern tactical air warfare (Horn, 1976). A common deterrent to effective voice communication in an operational environment is the use of electronic jamming techniques by the enemy. The Air Force has initiated extensive efforts to develop and implement effective jam-resistant voice communications. One of these efforts is the development of new, special-purpose radio systems with highly efficient jam-resistant characteristics. Effective jam-resistance for voice communications may be achieved by a number of different signal processing techniques. However, the effectiveness of the resulting processed signals as a voice communication link has yet to be demonstrated. This is particularly true with respect to the intelligibility and acceptability of the processed signal to the listener. Consequently, it is imperative that the various solutions to the problems of voice communications jamming be investigated to define the intelligibility and acceptability of the processed signal to the listener. Thereby no degradation of performance or interference with mission accomplishment due to an inadequate communication signal will be insured.

One approach to the problem of jam-resistant voice communications is the use of spread-spectrum techniques (Dixon, 1975). Radio systems have been developed that incorporate a spread-spectrum, jam-resistant principle with some success. However, the acceptability and intelligibility of the resulting voice communication signals have not been extensively evaluated. Two investigations of the performance of the latter aspect of spread spectrum radio system signals have recently been accomplished at the Aerospace Medical Research Laboratory.

A study (Bauer, 1977) investigated the word intelligibility of a spread-spectrum radio system under two modulator/demodulator systems (modems) and a range of jamming conditions. Volunteers responded to Diagnostic Rhyme Test (Voiers, 1967) word lists under eight different jammer-to-signal (J-S) power ratios presented over a standard aircraft intercommunication system (AIC-25) and standard inflight headsets. No external ambient noise was added to the test conditions, because the primary objective of the study was to assess the effects of the J-S power ratios on word intelligibility. Results of this study (Fig. 1) demonstrated that percent DRT word intelligibility (corrected for guessing) remained relatively constant as J-S power ratio was increased up to J-S level 5. As J-S was further increased up to J-S level 8, intelligibility decreased 30% for modem II and 60% for modem I. The performance of the two modems was generally equivalent up to J-S level 6, modem I being better at J-S level 7 and essentially unintelligible at J-S level 8.

The present study takes the next logical step in the continued evaluation of the same spread spectrum radio system by extending the test condition employed by Bauer to a practical situation. Specifically, the relative performance of the radio with respect to word intelligibility was measured under various experimental conditions in the presence of the simulated operational noise environment of a high performance aircraft. The questions addressed were

- Over a range of jammer to signal power ratios does the presence of simulated operational noise differentially affect the intelligibility of words processed over two modems of a sampled data, spread spectrum radio system?

- Will different levels of simulated operational noise result in corresponding changes in word intelligibility of the processed communication signal?

METHOD

APPROACH

The comparative intelligibility of standardized test materials processed through two sampled data, spread spectrum modems was measured in the presence of jamming. Volunteer listeners wearing standard inflight helmets responded to the communication signals in the presence of two different levels of a simulated operational noise. Decrements in percent intelligibility were attributed to various conditions of the jamming signal and to the presence of the simulated operational noise. Some characteristics of the jamming and noise signals important to effect voice communications were identified.

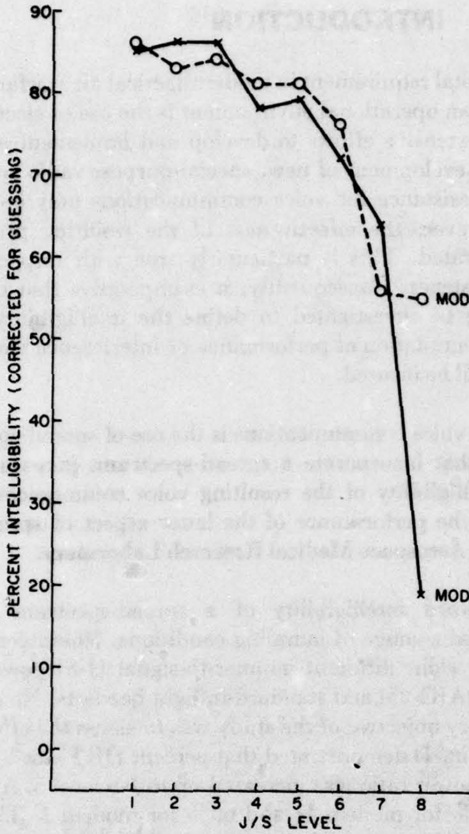

Figure 1. Percent intelligibility (corrected for guessing) for two modems of a spread spectrum radio system at various jammer-signal (J-S) power ratios. These tests were run in the absence of environmental noise and the measurement instrument was the Diagnostic Rhyme Test. The data are from Bauer (1977).

SUBJECTS

Nine subjects, seven female and two male, were employed in the present study. All were recruited from the general civilian population. They were paid at an hourly rate for their participation, with a cash bonus awarded when the subject completed all sessions. The hearing levels of all subjects were no greater than 15 dB at any standard audiometric test frequency from 500 to 6000 Hz.

FACILITIES

This experiment was accomplished in the voice communication testing facility of the Aerospace Medical Research Laboratory. The facility consists of a control room and a large reverberation room that has been equipped to simulate the voice communication and acoustic environments of inflight aircraft.

The overall system includes a master control station and ten individual aircraft communication stations. Each station contains the Air Force standard intercommunication system (AIC-25) and respiration system (A-19 Oxygen Regulators). Both intercommunication and respiration terminals and operating controls are easily accessible to the individual positioned at the station.

For this study all volunteers wore the standard Air Force Flight Helmet, HGU-26/P with the H-154A earcup assembly. Helmets were individually fitted to each subject by personnel of the AMRL Human Engineering Division. Either the MBU-5/P or MBU-12/P AF standard oxygen mask with the M-101 noise cancelling microphone was worn by each volunteer. Compressed air was respired through A-19 Diluter Demand Pressure Breathing Regulators set at normal operation by all subjects during the talking and listening phases of the evaluation.

The measurement instrument was the Modified Rhyme Test (MRT) as developed by House, Williams, Hecker, and Kryter (1963) for assessing communications effectiveness. The MRT was selected for use over other test materials because of evidence that it is the test of choice for evaluating the performance of military speech communication systems in the presence of environmental noise (Webster and Allen, 1972). The materials consist of lists of 50 one-syllable words that are equivalent (lists) in intelligibility. The MRT is easy to administer, score, and evaluate and it does not require extensive training of listeners. Listeners are provided preprinted answer sheets with six possible responses for each test word. The listener simply marks the word he or she thought was heard as the stimulus. To compensate for correct answers obtained by guessing a correction factor was applied to the scores.

MRT word intelligibility has been sufficiently standardized to allow the relative intelligibility of such materials as closed message sets and sentences to be estimated on the basis of the corresponding measured MRT scores.

The acoustic environment simulation facility consists of a large reverberation chamber that houses a powerful electrodynamic sound system. The electrodynamic system contains dual amplifiers that may be used singly or in combination. One system (low power) consists of two 200-watt amplifiers and the other (high power) consists of two 7000-watt amplifiers. The amplifiers drive 32 loudspeaker enclosures, each containing three 15-inch loudspeakers and twelve 3-inch high frequency "tweeters." The loudspeaker enclosures are portable and may be rearranged for various purposes. In the present configuration, as the enclosures are arranged for this study, the low power system generates a maximum overall sound pressure level (SPL) of 122 dB while the high power system generates a maximum overall SPL of 128 dB re 20μPa (with a pink noise input).

The low power system was used in the cockpit noise environment simulation. A pink noise source was shaped by a 1/3 octave band spectrum shaper (or filter bank) so that the spectrum measured in the test space matched that of an F-15A cockpit noise spectrum provided by McDonnell-Douglas Corporation. The resulting spectra for the two levels used in this study, 105 and 115 dB, are shown along with the measured cockpit noise data in Table 1. It is clear that the simulated acoustic environments are accurate reproductions of the actual operational noises, except at 63 Hz where an amplifier hum produced a little more energy in the simulated spectra.

TABLE 1

Measured and simulated spectra of F-15A cockpit noise at overall sound pressure levels of 105 dB and 115 dB. Measured noise was taken at position of pilot's left ear while aircraft was in cruise mode of operation.

Octave Band Center Frequency Hz	*McDonnell Douglas Measured Spectra*		*Aerospace Medical Research Laboratory Simulated Spectra*	
	105 dB	*115 dB*	*105 dB*	*115 dB*
31.5	74	84	74	83
63.0	79	89	94	103
125.0	101	111	100	111
250.0	97	107	96	106
500.0	96	106	97	107
1000.0	97	107	96	107
2000.00	88	98	89	99
4000.00	85	95	88	95
8000.0	95	105	96	104
Overall	105	115	105	115

The spread spectrum radio system and the jamming-to-signal power ratios being evaluated were the same as those described and evaluated by Bauer (1977). The standardized communication signals were processed by the radio and then presented to the listeners through the standard AF aircraft intercommunication system and terminal equipment.

The method used to simulate the jamming signal was identical with that employed by Bauer (1977). A broadband jamming signal centered at the transmitter intermediate frequency was produced by modulating a sinusoidal tone. All connections between the transmitter, receiver, and jammer were made by means of standard 50-ohm coaxial cable, thus allowing precision step attenuators to be used to vary the J-S power ratio.

EXPERIMENTAL PROCEDURE

The present experiment was so designed that each subject served as his or her own control, i.e., each subject participated in all experimental conditions. Order of presentation of experimental conditions was randomized and subjects performed as both talkers and listeners in a "round-robin" fashion. The talker on any one trial served as a listener on previous and subsequent trials. The parameters investigated were jammer-to-signal power ratios and two levels of simulated cockpit noise (105 and 115 dB overall). Subjects participated for 3 hours per day in experimental sessions of about 40 minutes followed by 15-minute rest periods, for 12 days. All nine subjects were run simultaneously within the Communication Testing Facility. A block diagram of the experimental setup is shown in figure 2.

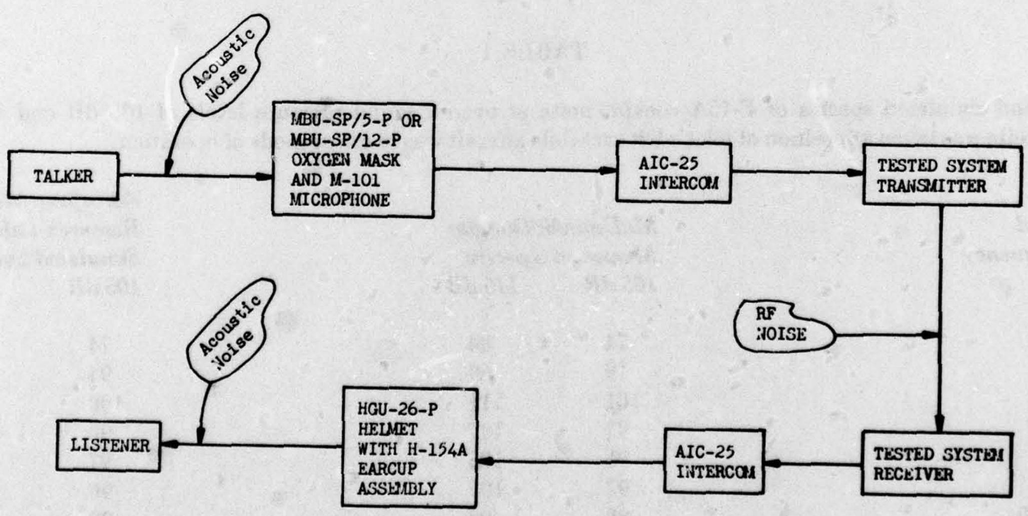

FIGURE 2 BLOCK DIAGRAM OF EXPERIMENTAL EQUIPMENT

RESULTS

The percent correct intelligibility values resulting from the experimental measurements of this investigation are summarized in figure 3. Changes in word intelligibility as a function of J-S power ratio and of the presence of 105 dB simulated operational noise are displayed for the two modems evaluated in curves A and B. The general decrease in intelligibility with increasing J-S power ratios is evident. However, it is also apparent that an interaction exists between the modems tested and the J-S power ratios. The difference between modem means at each J-S power ratio was tested for significance with two tailed t-tests (Edwards, 1960, pp. 90-94). At J-S levels 1 and 3 modem I is significantly more intelligible ($p<.05$). A J-S level 4 yields equivalent intelligibility scores for the two modems. Modem II is significantly more intelligible ($p<.01$) at J-S levels 5 and 6, while at J-S level 7 the curves cross once again with modem I being significantly more intelligible ($p<.01$). Particularly confusing is the increase in intelligibility (from 44 to 51%) for modem II from J-S level 4 to level 5. Detailed examination of individual scores at J-S level 5 revealed that an increase in intelligibility compared to that obtained at J-S level 4 was exhibited by all but one of the subjects, thus the increase appears to be a real one and not due to one or two aberrant scores. Except for the instance mentioned above, increasing the J-S power ratio generally resulted in intelligibility remaining the same or decreasing. Overall for modem I intelligibility decreased from 58% at J-S level 1 to 29% at J-S level 7, modem II decreased from an intelligibility score of 52% at J-S level 1 to 19% at level 7.

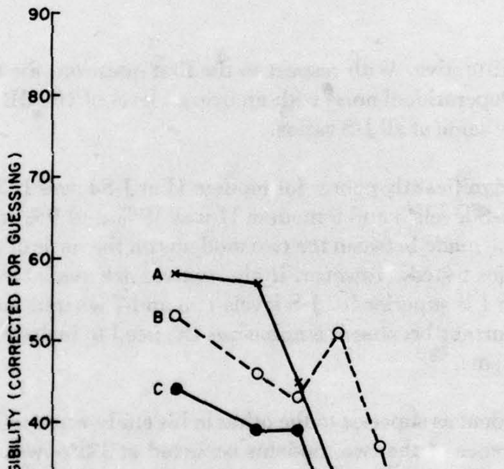

Figure 3. Percent intelligibility (corrected for guessing) for two modems of a spread spectrum radio system at various jammer-signal (J-S) power ratios. These tests were run in a simulated F-15A cockpit noise environment. Curve A is for Modem I in 105 dB overall, curve B is Modem II in 105 dB overall, and curve C is Modem I in 115 dB overall. The measurement instrument employed was the Modified Rhyme Test.

The changes in percent correct word intelligibility for modem I as a function of J-S power ratio in the presence of two different levels of simulated operational noise (105 dB and 115 dB overall) are observed in curves A and C. Overall the trend of the two functions is quite similar with increasing J-S power ratio resulting in less intelligibility. In the presence of 105 dB noise, intelligibility decreased from 58% at J-S level 1 to 27% at level 6, while intelligibility decreased from 44% at J-S level 1 to 21% at level 6 in the presence of 115 dB noise. At all J-S power ratios the function for intelligibility in the presence of 115 dB noise was lower than that for intelligibility in the presence of 105 dB noise. The differences between means at each J-S power ratio were tested with two-tailed t-tests. All differences were significant, with those at J-S levels 1, 3 and 5 having a $p<.01$ and those at J-S levels 4 and 6 having $p<.05$.

DISCUSSION

This research addressed the following questions:

- Under a range of jammer-to-signal power ratios, does the presence of simulated operational noise differentially affect the intelligibility of words processed over two modems of a sampled data, spread spectrum radio system?
- Do different levels of simulated operational noise result in corresponding changes in word intelligibility?

The answers to both questions were affirmative. With respect to the first question, the two modems were differentially affected by the presence of a simulated operational noise with an overall level of 105 dB. However, the effect measured was not a simple one, i.e., it was not the same at all J-S ratios.

The word intelligibility measured was significantly poorer for modem II at J-S levels 1, 3 and 7 (ranging from 6 to 11% poorer relative to modem I), while at J-S levels 5 and 6 modem II was 19% and 9% more intelligible than modem I. From these results no clear choice can be made between the two modems on the basis of their overall performance in the presence of noise for the J-S power ratios tested. However, if alternatives are available within the range of J-S power ratios measured, it is clear that modem I is superior for J-S levels 1, 3 and 7 whereas modem II would be superior for levels 5 and 6. This finding is also important because it emphasizes the need to include environmental factors, such as noise in evaluating communication systems.

Bauer (1977) could not identify one modem as superior to the other in his study when testing without noise (Fig. 1). The only significant differences in performance of the two modems occurred at J-S power ratios of 7 and 8. Overall, the present study likewise provides no overriding conclusion, however, it does, in the presence of the noise environments, show that the performance of the modems differ and that one is definitely superior to the other at specific J-S power ratios.

The second question was examined in the present study by comparing word intelligibility of modem I in simulated operational noise at overall sound pressure levels of 105 dB and 115 dB. Increasing the noise level from 105 to 115 dB resulted in a significant decrement in intelligibility at all J-S power ratios tested. This decrement ranged from 18% at J-S level 2 to 6% at level 6. When compared to Bauer's data (Fig. 1) the presence of 105 dB simulated noise resulted in a decrement of intelligibility for modem I of approximately 30% for all J-S power ratios compared.

Given these MRT word intelligibility scores and their relationship to other types of speech materials (Kryter, 1972), an estimate can be made as to the intelligibility that would be expected for sentences known to the listener. Specifically, the sentence intelligibility expected under the conditions evaluated in this study can be estimated for pilots using this radio system operating configuration in operational situations. As summarized in Table 2, at J-S level 1, word intelligibility scores of 85% (DRT) in the absence of ambient noise, 58% (MRT) in presence of 105 dB noise and 44% (MRT) in presence of 115 dB noise would yield intelligibility scores for sentences known to the listeners of approximately 96%, 83%, and 70% respectively. At J-S level 6, word intelligibility scores for the same three noise conditions of 69%, 27% and 21% yield intelligibility scores for known sentences of approximately 90%, 53% and 28% respectively. Decrements of this magnitude strongly argue for the desirability of evaluating prospective airborne speech

communication systems in a simulated cockpit noise environment. Although there are no standards established that determine at what point a communication system is not operationally useful, intuitively it would appear that an intelligibility of at least 80% for sentences known to the listener would be minimally essential.

TABLE 2

Estimate of percent intelligibility of sentences known to the listener given percent word intelligibility.

	AMBIENT NOISE LEVEL					
J-S	*NONE*		*105 dB*		*115 dB*	
	DRT	*KNOWN SENTENCES*	*MRT*	*KNOWN SENTENCES*	*MRT*	*KNOWN SENTENCES*
1	86	96	58	83	44	70
3	84	95	56	83	39	63
4	78	93	45	70	38	63
5	78	93	32	54	25	36
6	69	90	27	53	21	28

Data is for modem I under three ambient noise levels (computed from Kryter, 1972, p. 175).

CONCLUSION

A laboratory evaluation has been conducted of the resistance to jamming of a spread spectrum radio operating at two different modems in the simulated noise of an aircraft cockpit. Word intelligibility was degraded by increased jamming conditions and by the presence of the simulated aircraft noise. In general, neither modem was superior overall to the other under all conditions tested. However, at specified jammer-to-signal power ratios a clear advantage could be demonstrated for one modem over the cther and the modem advantage alternated depending on the jammer-to-signal power ratio.

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